Atrial Tachyarrhythmias After the Maze Procedure
Incidence and Prognosis

Yosuke Ishii, MD; Marye J. Gleva, MD; M. Carolyn Gamache, MD; Richard B. Schuessler, PhD; John P. Boineau, MD; Marci S. Bailey, RN; Ralph J. Damiano, Jr, MD

Background—The Maze procedure restores normal sinus rhythm in the majority of patients. However, atrial tachyarrhythmias (ATA) are a common early complication after the operation. The purpose of this study was to define the incidence and natural history of ATA after the Maze procedure.

Methods—Complete medical records from 200 patients who underwent the Maze procedures (I, II, and III) from 1987 to 2002 were examined for all episodes of early postoperative ATA that occurred during the first 30 days after the procedure. Two electrophysiologists independently reviewed all postoperative 12-lead electrocardiograms.

Results—ATA occurred in 86 patients (43%) after the Maze procedure. Of the patients with ATA, 59% had atrial fibrillation (AF), 14% had atrial flutter (AFL), and 27% had both AF and AFL. Of the patients with AF or AFL, 20% and 5%, respectively, also had episodes of atrial tachycardia and supraventricular tachyarrhythmia. The peak incidence of early postoperative ATA was on postoperative day 8. The average duration of ATA was 5.7 days. Late recurrence of AF (>1 year postoperatively) occurred in 7.0% of patients who had early postoperative ATA and 8.8% of patients without early postoperative ATA (P=0.8).

Conclusions—ATA occurred in 43% of patients after the Maze procedure. The tachyarrhythmias occurred primarily within 8 days after surgery and resolved within 3 weeks in almost all patients. There was no relationship between the incidence of early postoperative ATA and the late recurrence of AF. (Circulation. 2004;110[suppl II]:II-164–II-168.)

Key Words: arrhythmia • fibrillation • surgery • tachyarrhythmias

Postoperative atrial tachyarrhythmias (ATA) are relatively common after cardiac surgery.1–3 These tachyarrhythmias are recognized as a major cause of perioperative morbidity. They can cause hypotension, congestive heart failure, and significant symptoms that include palpitations or shortness of breath. Moreover, the management of these arrhythmias has been shown to significantly extend the length of hospitalization.4,5

The Maze procedure has evolved into the gold standard of treatment for medically refractory atrial fibrillation (AF) during the past decade. The atrial incisions of the procedure are designed to block potential macroreentrant pathways and narrow the atrial tissue to block propagation of microreentrant wavelets. Moreover, focal activation from pulmonary veins is blocked by the isolation of left atrial posterior wall, including all of the pulmonary veins.6 Studies show that the procedure restores normal sinus rhythm in >90% of patients at late follow-up.6–9 However, 40% of patients undergoing the Maze procedure have early postoperative ATA, despite the fact that the Maze procedure effectively prevents late AF.10

The incidence of ATA has been well-described after cardiac procedures. Previous studies have shown that the peak incidence of early postoperative AF is on the second postoperative day (POD) after coronary artery bypass surgery, with more than one-third of such episodes occurring on that day.2,5 Of patients who experience early postoperative AF, 87% will do so by the end of POD 5. It has been shown that patients having valvular surgery have a higher incidence of early postoperative AF compared with coronary artery bypass patients.1,4,11,12

However, ATA after the Maze procedure have not been examined in detail. The purpose of this study was to define the incidence and natural history of early postoperative ATA after the Maze procedure, and to examine whether the occurrence of these arrhythmias predisposed to late recurrence of AF.

Methods

Patient Population
Between September 25, 1987 and July 1, 2002, a total of 252 adult patients underwent the Maze procedure at Barnes–Jewish Hospital at...
Preoperative medications, including digoxin and β-blockers, were routinely withdrawn on the day of surgery. Although the use of prophylactic antiarrhythmia medications was variable, all patients with early postoperative ATA were treated with either a class I or a class III antiarrhythmic drug. Oral anticoagulation was maintained for the first 2 to 3 months. Nineteen patients (9.5%) had a pacemaker that had been implanted before their Maze procedure. One hundred fifty-five patients (78%) received temporary atrial pacing for at least 1 day after the Maze procedure. Fifty-two patients (26%) required a pacemaker implantation after the Maze procedure (Maze I, 17 of 30 patients; Maze II, 4 of 12 patients; Maze III, 31 of 158 patients).

Study Protocol

All early postoperative 12-lead ECGs (<30 days after surgery) were reviewed according to standard electrocardiographic criteria by 2 electrophysiologists (M.J.G., M.C.G.) who were blinded with respect to POD and patient characteristics. All patients were monitored continuously for arrhythmias until the time of discharge from the hospital. While patients were in the intensive care unit, monitoring was performed using individual bedside electronic monitors. When patients were in the postoperative nursing ward, monitoring was performed by telemetry to a central nursing station monitoring system. For the purpose of this study, atrial tachyarrhythmias were defined to be any episodes of one or more of the following tachyarrhythmias: AF, atrial flutter (AFL), atrial tachycardia, or supraventricular tachyarrhythmia (SVT).

Definitions

AF was defined as a rapid irregular rhythm with disorganized atrial activity in which distinct P waves were absent. AFL included both typical and atypical forms. Typical flutter was a regular atrial arrhythmia with negative flutter waves in the inferior leads and positive flutter waves in lead V1 at an atrial cycle length of 200 to 280 ms. Atypical flutter encompassed regular atrial activity at similar cycle lengths with monophasic or monomorphic flutter. Atrial tachycardia was defined as a heart rate >100 bpm with a P-wave morphology and axis different from the sinus P wave. SVT was defined as the sudden onset of a rapid atrial rate (150 to 200 bpm) with a regular narrow QRS complex and no obvious P waves.

Follow-Up

The patients’ clinical profiles and postoperative outcomes were recorded in a computerized database. Long-term follow-up was conducted by a mailed questionnaire or telephone interview with patients and also contact was made with either their cardiologist or their primary care physician. To confirm arrhythmia recurrence, copies of ECG and Holter monitoring were required. The average follow-up period was 103 ± 37 months (15 to 189 months).

Statistical Analysis

All continuous values were expressed as mean ± SD. The continuous variables were compared between the procedures by an analysis of variance. Tabular data were compared using the χ² or Fisher exact test. Univariate and multivariable stepwise logistic regression was used to identify the significant predictors of postoperative AF. The following variables were entered into the model: patient age, type of preoperative AF, duration of preoperative AF, the Maze procedure version (I to III), cross-clamp time, and cardiopulmonary bypass time. A value of P < 0.05 was considered statistically significant (SYSTAT, v10.2, SYSTAT Software).

Results

Eighty-six patients (43%) had one or more episodes of ATA in the early postoperative phase (<30 days) after the Maze procedure (Figure 1). The other 114 patients did not have any early postoperative ATA. Of the patients who had ATA, 51 patients (59%) had AF, 12 patients (14%) had AFL, and 23 patients (27%) had both AF and AFL (AF + AFL). Atrial tachycardia also occurred in 17 patients with AF or AFL (9 AF patients, 2 AFL patients, and 6 AF + AFL patients). SVT occurred in 4 patients with AF or AFL (3 AF patients and 1 AF + AFL patient). Atrial tachycardia or SVT did not occur in any patients who also did not experience AF or AFL.
mean atrial cycle lengths of AFL and AT were 207±13 ms (200 to 240 ms) and 401±79 ms (270 to 560 ms), respectively. The mean atrial cycle length of SVT was 300±23 ms (280 to 320 ms).

The peak incidence of early postoperative ATA was on POD 8, with 18% of such episodes occurring on that day (Figure 2). The incidence of early postoperative ATA was clustered within first 14 days after the Maze procedure. By the end of POD 14, 87% of patients with early postoperative ATA had experienced their tachyarrhythmias. The incidence of early postoperative ATA decreased markedly after POD 14. Only one patient still had ATA after the third postoperative week.

In 93% of the patients with the early postoperative ATA, the initial onset of the ATA occurred within the first 9 postoperative days (Figure 3). The average duration of early postoperative ATA was 5.7±5.0 days. In 74% of the patients with ATA, the duration was >24 hours. Despite the use of antiarrhythmic drugs, early postoperative ATA continued in 42 patients >5 days after the Maze procedure. However, only 5 patients continued to experience ATA >2 weeks postoperatively.

Early postoperative ATA occurred in 47% of patients with preoperative continuous AF and 40% of patients with preoperative paroxysmal AF (P=0.3). In 123 patients with a preoperative diagnosis of lone AF, 53 patients (43%) had postoperative ATA. On univariate analysis, the only preoperative factors associated with a higher incidence of postoperative ATA were mean age of the patient (P=0.003) and a longer duration of preoperative AF (P=0.08, Table 2). The intraoperative factor associated with a higher incidence of postoperative ATA was cardiopulmonary bypass time (P=0.04). Length of hospital stay in early postoperative ATA patients was significantly longer than that of patients without early postoperative ATA (P=0.00002), despite the same length of intensive care unit stay in each group (P=0.3).

In 30 patients who underwent the Maze I procedure, 17 patients (57%) had early postoperative ATA. Early postoperative ATA occurred in 6 (50%) of 12 Maze II patients and in 63 patients (40%) of 158 Maze III patients, respectively. There was no significant difference of incidence of early postoperative ATA between Maze I, II, and III procedures (P=0.2).

In the 133 patients with the Maze procedure alone, 52 patients (39%) had early postoperative ATA. Thirty-two patients of the 59 patients with the Maze procedure and a concomitant procedure (coronary artery bypass grafting or valvular surgery) had early postoperative ATA. The incidence of early postoperative ATA was significantly lower in the patients with the Maze procedure alone (P=0.04; Table 2). There was a trend that the patients undergoing the Maze

### TABLE 2. Univariate Analysis for Early Postoperative ATA

<table>
<thead>
<tr>
<th></th>
<th>ATA (n=86)</th>
<th>No ATA (n=114)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>56.1±11.2</td>
<td>51.2±10.7</td>
<td>0.003</td>
</tr>
<tr>
<td>Duration of preoperative AF, y</td>
<td>10±9</td>
<td>8±7</td>
<td>0.08</td>
</tr>
<tr>
<td>Cross-clamp time, min</td>
<td>95±30</td>
<td>97±32</td>
<td>0.6</td>
</tr>
<tr>
<td>Cardiopulmonary bypass time, min</td>
<td>186±35</td>
<td>175±39</td>
<td>0.04</td>
</tr>
<tr>
<td>Concomitant Procedures</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maze alone</td>
<td>52 pts (26%)</td>
<td>81 pts (40.5%)</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Valvular surgery or CABG</td>
<td>32 pts (16%)</td>
<td>27 pts (13.5%)</td>
<td>0.5</td>
</tr>
<tr>
<td>Other procedures</td>
<td>2 pts (1%)</td>
<td>6 pts (3%)</td>
<td>0.2</td>
</tr>
<tr>
<td>Length of ICU stay, d</td>
<td>4±3</td>
<td>3±4</td>
<td>0.3</td>
</tr>
<tr>
<td>Length of hospital stay, d</td>
<td>14±6</td>
<td>11±6</td>
<td>0.00002</td>
</tr>
<tr>
<td>Late recurrence of AF</td>
<td>7.0%</td>
<td>8.8%</td>
<td>0.8</td>
</tr>
</tbody>
</table>

ATA indicates atrial tachyarrhythmias; AF, atrial fibrillation; CABG, coronary artery bypass grafting; ICU, intensive care unit.

Other procedures: atrial septal defect repair (n=5), septal myectomy (n=1), myxoma resection (n=1), and repair of cor triatriatum (n=1).
TABLE 3. Univariate and Multivariate Predictors Analysis of Early Postoperative ATA  

<table>
<thead>
<tr>
<th></th>
<th>Univariate Analysis</th>
<th>Multivariate Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>0.003</td>
<td>0.03</td>
</tr>
<tr>
<td>Type of preoperative AF</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>Duration of postoperative AF</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Maze procedure version (I–III)</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Concomitant procedures</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Cross-clamp time</td>
<td>0.17</td>
<td>0.17</td>
</tr>
<tr>
<td>Cardiopulmonary bypass time</td>
<td>0.06</td>
<td>0.06</td>
</tr>
</tbody>
</table>

procedure with a concomitant procedure had a higher incidence of early postoperative ATA than the patients with the Maze procedure alone ($P=0.06$; Table 3).

Stepwise logistic regression identified age ($P=0.007$), cross-clamp time ($P=0.037$), and cardiopulmonary bypass time ($P=0.026$) as the only significant predictors of early postoperative ATA (Table 3).

Anti-arrhythmia medication at late-term follow-up was available in 184 (92%) of the 200 patients. Of 184 patients with follow-up, 11 patients (6%) were using a class I anti-arrhythmic drug and 6 patients (3%) were using a class III drug at last follow-up. The indications for the usage of these drugs were at the discretion of the patient’s cardiologists.

Electrophysiology studies and catheter ablation were performed in 12 patients in whom atrial tachyarrhythmias developed after the Maze procedure. Six patients had AFL at the time of electrophysiology study. All of these patients were found to have the flutter circuit confined to the left atrium. Two patients were ablated by radiofrequency or direct current (DC) energy applied to the coronary sinus, because coronary sinus conduction had recovered after the application of operative cryothermia lesions to a degree that allowed conduction from the left to right atrium. One patient was treated with anti-arrhythmic medications. Three other patients underwent radiofrequency ablation of the AV node with pacemaker implantation. Two patients had AF diagnosed at electrophysiology study after the Maze procedure. These patients were also treated by AV node ablation and pacemaker implantation. Four patients had atrial tachycardia diagnosed in the electrophysiology laboratory. In each case, the site of origin was localized to the right atrium. All were treated with radiofrequency ablation. One patient required 2 procedures to terminate the atrial tachycardia.

Of 11 patients who required the catheter ablation, 5 patients had had early postoperative ATA after the Maze procedure (AF, 4 patients; AF + AFL, 1 patient; and AFL, 1 patient). The other 5 patients had never had any ATA in early postoperative phase.

Sixteen patients (8.0%) had recurrence of AF in the late postoperative period (>1 year) after the Maze procedure. Of the patients with early postoperative ATA, 7.0% experienced late recurrence of AF. Of the patients without early postoperative ATA, 8.8% experienced late recurrence of AF. There was no significant difference in the late recurrence of AF between these 2 groups ($P=0.8$) (Table 2).

Discussion

There were several important findings in this study. First, there was no relationship between the incidence of early postoperative ATA and the late recurrence of AF after the Maze procedure. Early postoperative ATA was most often transient and usually terminated within the first several weeks after the Maze procedure. The most common arrhythmias were AF and AFL. The peak incidence of early postoperative ATA was on POD 8 and 87% of patients with ATA had their episodes within the first 2 weeks after surgery.

The Maze procedure cures AF and restores sinus rhythm in the majority of patients. Even though the Maze procedure is designed to cure AF, early postoperative ATA occurred in >40% of patients after the Maze procedure in the present study. Other studies have shown that AF emerges after pulmonary vein (PV) isolation by radiofrequency ablation. After complete PV isolation by catheter ablation, 35% of those patients were found to have AF on POD 4. In one-third of those patients, the early recurrence of AF converts to sinus rhythm 2 weeks after the catheter ablation.

The mechanism of early postoperative ATA may be different from that of preoperative AF. The increased dispersion of atrial refractoriness is one proposed mechanism that facilitates the initiation of reentry in the atria after surgery. Some studies also have shown that an increased inflammatory response correlates with the occurrence of early postoperative ATA. Chung et al showed that patients with AF had higher C-reactive protein levels than patients without AF. The Maze procedure requires extensive incisions and suture lines on both atria. Inflammation in the atrial myocardium caused by the atrial incisions may be associated with early postoperative ATA. Unfortunately, we were not able to investigate atrial inflammation after the Maze procedure in this retrospective study. The Ca²⁺ channel may also play a role in early postoperative AF. A higher Ca²⁺ current density in the atrial myocytes has been described in patients with early postoperative AF. Furthermore, the present study showed the significance of cross-clamp time and cardiopulmonary bypass time in predisposing to early postoperative ATA. Atrial ischemia during cardiac surgery may be one of the mechanisms of early postoperative ATA. Simo et al have demonstrated that atrial ischemia causes slow conduction in the ischemic zone, resulting in a substrate for AF maintenance.

Incomplete cryoablation near the valvular annulus or coronary sinus during the Maze procedure has been postulated to incisonal macroreentry around the mitral or tricuspid valves. Shah et al described slow conduction through the isthmus created by incomplete ablation causing sustained stable AFL. Avoidance of incomplete ablation could prevent incisonal macroreentry after the Maze procedure. Nonpulmonary vein focal tachycardia may also occur after the Maze procedure. In this study, 4 patients had right atrial tachycardia that was treated with radiofrequency catheter ablation after surgery.
In coronary artery bypass surgery patients, 2 large observational studies have investigated the timing of the onset of early postoperative ATA.\textsuperscript{2,5} Those studies showed that the peak incidence of ATA is on POD 2 after coronary artery bypass surgery. In contrast, the incidence of onset of early postoperative ATA was much later in patients after the Maze procedure. Therefore, the incidence of postoperative ATA significantly lengthened hospital stay after the Maze procedure. Similar to coronary artery bypass surgery patients, however, postoperative early ATA after the Maze procedure appeared to be self-limiting and without any long term detrimental influences on patient prognosis.

Patient age is an important risk factor for early postoperative AF after other cardiac procedures.\textsuperscript{3,5,11} Aranki et al showed that the incidence of early postoperative AF was 52% for patients older than 80 years compared with 18% for patients younger than 60 years in coronary artery bypass grafting patients.\textsuperscript{5} In the present study, the mean age of patients with early postoperative ATA was significantly higher than that of patients without early postoperative ATA after the Maze procedure. Age-related atrial structural changes, such as dilatation, atrophy, or fibrosis, might affect the occurrence of early postoperative ATA.

The data in this study describe the national history of ATA after the Maze procedure in a large cohort of patients. The most significant risk factors for the development of postoperative ATA were patient age, cross-clamp time, and cardiopulmonary bypass time. The early postoperative ATA usually resolved within 3 weeks after the Maze procedure, and most importantly had no significant relationship to the late recurrence of AF after the Maze procedure.

References
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